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TO ALL WHOM IT MAY CONCERN:

Be it known that we, Allen E. Blackburn and Fatai Odebesi, citizens of the United States, residing in Reading, Pennsylvania, and Mohton, Pennsylvania, respectively, and whose post office addresses are 4729 Alisan Road, Reading PA, and 515, Alleghenyville Rd., Mohton Pa, 19540, respectively, have invented an improvement in

METHOD AND APPARATUS FOR PERIMETER CLEANING IN COLD HEARTH REFINING

of which the following is a

SPECIFICATION

BACKGROUND OF THE INVENTION

This invention relates to cold hearth melting and refining of reactive and refractory materials. In particular, this invention relates to improvements to electron beam cold hearth melting and refining apparatus and processes.

Cold heart refining processes are now commonly employed for the production of reactive and refractory metals such as tantalum, niobium, molybdenum, tungsten, vanadium, hafnium, zirconium, titanium and their alloys. In electron beam cold hearth refining (EBCHR) processes, electron beams are used to melt target raw metals that are placed under high vacuum in water-cooled hearths. Metallic and non-metallic impurities having vapor pressures higher than those of the base constituents selectively evaporate from the molten material. Thus, the base constituent of the target material is purified.

In conventional EBCHR apparatus, the hearths are usually elongated copper troughs or crucibles, which are water-cooled. The hearths are configured to receive a charge of target material (e.g., titanium scrap or lumps) from one end or side (e.g., by gravity feed). One or more electron guns are configured to direct electron beams to the surface of the target material to melt and form shallow surface pools of liquid metal in the hearth. The molten metal in the surface pools flows along the hearth and then overflows from the hearth into a water-cooled mold. The hearths usually have distinct melting and refining regions. The melting region is at the end where the target material is introduced and the refining region extends from the melting region toward the overflow mold. The shallow pools of liquid metal (i.e., molten material) in the two regions are connected by a narrow channel through a skull of solid material that separates the two regions. Advantageously in the refining process, high- and low-density inclusions are also removed from the molten material in addition to the selective evaporation of volatile impurities. High-density inclusions settle and collect in the skull, while lighter inclusions either are dissolved in the liquid metal or are held back by a dam or other physical barriers prior to flowing into the mold.

In the operation of EBCHR apparatus, the electron beams are scanned over the surface of the target material to sustain the liquid state of the molten material in the melting and refining regions. Conventional electromagnetic deflectors, which may be computer controlled, are used to move the electron beams. By scanning the electron beams in suitable geometrical patterns, heat is applied to selected portions of the surface of the target material so that a liquid stream of metals flows from one end of the hearth to the other. Exemplary EBCHR apparatus are described in co-assigned Harker United States patent No. 4,932, 635 and United States patent

No. 4,961, 776, and Harker et al. United States patent No. RE32,932, all of which are incorporated by reference in their entireties herein.

In the continuous operation of the EBCHR apparatus, the volatile impurities that evaporate from the liquid stream often recondense and accumulate along the cooler banks or perimeter of the liquid stream. Additionally, inclusions in the molten liquid may also collect and accumulate along the perimeter of the liquid stream. In time these accumulations can become large and interfere or even choke the flow of the liquid stream. To prevent this, it is necessary to clear the buildup of accumulated material on the perimeter of the liquid stream. In practice, a human operator observes the buildup of the accumulated material on the perimeter of the liquid stream, and periodically directs an electron beam to clear blocking or interfering accumulations from the perimeter of the liquid stream. The operator manually sets the position and the dwell times of the electron beam at specific spots, for example, using a joystick, to melt or vaporize on the undesirable accumulations. The continuity of the refining process is thus dependent on the availability and skill of a human operator.

Consideration is now being given to ways of enhancing both the processes and apparatus to improve the overall efficiency of electron beam cold hearth refining systems. Particular attention is directed to cleaning or removal of undesirable accumulations on the perimeters of the liquid streams.

SUMMARY OF THE INVENTION

Accordingly it is an object of the present invention to provide a cold hearth melting and refining arrangement which overcomes the disadvantages of the prior art.

This and other objects of the invention are attained by incorporating an movable electron beam for perimeter cleaning in a cold hearth melting and refining arrangement. The electron beam automatically sweeps at least a portion of the perimeter of the pool of molten material that is formed in the melting and refining operations. The electron beam supplies heat to reevaporate, remelt or otherwise disperse volatile impurities that evaporate from the pool of molten material and recondense on the perimeter. The movement and the timing of the electron beam is controlled by a program loaded in a programmable logic controller or similar programmable device

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of the invention will be apparent from a reading of the following description in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic vertical sectional view illustrating a cold hearth melting and refining arrangement in accordance with the prior art;

FIG. 2 is a schematic horizontal sectional view illustrating the cold hearth melting and refining arrangement of FIG. 1;

FIG. 3 is a schematic illustration of aluminum wings formed on the perimeter of the liquid stream in the cold hearth melting and refining arrangement of FIG. 1;

FIG. 4 is a schematic representation of a cold hearth refining arrangement in accordance with the invention; and

FIG. 5 is a schematic representation of the path of an electron beam for cleaning the perimeter of a liquid stream in a cold hearth melting and refining arrangement in accordance with the invention.

DESCRIPTION OF PREFERRED EMBODIMENT

The present disclosure provides solutions for improved electron beam cold hearth melting and refining operations. A disclosed solution concerns cleaning the perimeter of the liquid stream of molten material that flows through the cold hearth.

The invention is suitable for improving the operation of EBCHR hearths, whose configurations may vary, for example, based on considerations of the type of material to the refined, throughput and other manufacturing parameters. Exemplary hearths, which can be used for refining titanium alloys, are described in Harker United States patent No. 4,932,635 and United States patent No. 4,961,776 (hereinafter "Harker"). In order that the invention herein described may be easily understood, the subsequent description is set forth with reference to the prior art cold hearths described by Harker. It will, however, be understood that the invention is equally applicable to other types or configurations of cold hearths. As an aid to the understanding of the present invention, a limited description of the cold hearths described by Harker is included herein. FIGS. 1 and 2, which for convenience are reproduced herein from Harker, respectively show vertical and horizontal sectional views of a prior art hearth,.

With reference to FIGS. 1 and 2, hearth 10 includes a melting region 17 and a refining region 18. Melting region 17 may have, for example, square dimensions of about 36" by 36". Refining region may have rectangular dimensions of about 36 " wide by about 6' long. Each region may be about 3" to 4" deep. In the operation of the hearth, both regions hold shallow pools of liquid material 19. The liquid material is contained by a skull 21 of resolidified material formed on a hearth bed 11, which is cooled by a coolant passing through cooling pipes 12. At an inlet end of hearth 10, a chute 13 directs pieces 14 of the raw material to be refined (e.g., titanium sponge or titanium alloy turnings) into melting region 17 of hearth 10. Electron guns 15, which produce controllable patterns of electron beams 16, are directed selectively on to regions 17 and 18. In the arrangement shown in FIG. 1, one of the electron beams 16 is directed on raw material 14 in region 17 of the hearth so as to melt that material. Liquid material 19 from region 17 can flow into region 18 through a narrow channel 28 extending through raised portions 27 of skull 21 between the two regions 17 and 18. Liquid material 19 flows through refining region 18 and exits hearth 10 through pouring lip 20 into mold 21. The refined liquid material is collected in mold 21 as liquid material 26 and then further cooled to solidify as refined ingot 23.

Two of the other electron beams 16 shown in FIG. 1 (to the right of the electron beam directed on raw material 14 in region 17) are computer controlled to automatically scan over central portions of the surface of refining region 18. These electron beams supply heat to sustain the liquid state of molten material 19 as it flows toward pouring lip 20. The scan paths of the electron beam are pre-programmed so electron beams 16 may scroll, for example, up and down the length of refining region 18. Some of the heat supplied by electron beams 16 is drawn out by the cooled sides of hearth 10 causing material adjacent to the cooled sides to solidify as

skull 21. Coolant pipes 12 that pass through hearth bed 11 are configured so that skull 21 forms or grows inward from the sides of hearth 10 with particular geometric shapes (see e.g. skull peninsulas 30 and 29, FIG. 5) to confine the liquid stream of molten material 19 in a suitable flow path of channel. Optionally or additionally, the scan paths of electron beams 16 may be designed to avoid heating selected portions of the material in hearth 10 to encourage growth of skull 21 in particular geometric shapes. The portions of skull 21 extending inward from the sides of hearth 10 (see e.g., FIGS. 2 and 5) form the cooler banks or perimeter of the liquid stream of molten material 19 flowing through hearth 10 toward pouring lip 20.

During the refining operations, volatile constituents evaporate from molten material 19 as it flows as a liquid stream through regions 17 and 18. The evaporated constituents can recondense on the cooler perimeter of the liquid stream. In the illustrative case of titanium or titanium alloy refining, aluminum is a known volatile constituent. The buildup or accumulation of recondensed aluminum on the perimeter of the liquid stream can be substantial. The recondensed or redeposited aluminum may initially form a slight crust and progressively accumulate as tall "skull wings" on the perimeter of the liquid stream. FIG. 3 schematically shows aluminum wings 300 deposited on the perimeter of molten titanium material 19. Over time, wings 300 may, for example, grow to be over 6 " inches high. Wings 300 can interfere with the electron beam heating of molten material 19 (e.g., by electrostatic charging). Wings 300 also may physically interfere with the flow of molten material 19.

In accordance with the present invention, the growth of skull wings and other redeposit of material on the perimeter of liquid stream is inhibited by an automatic perimeter cleaning process, which is integrated with the usual EBCHR operations. In the inventive

cleaning process, an electron beam (hereinafter "the cleaning beam") is programmed to automatically sweep over selected outward portions of the hearth (e.g., over the surface skull portions adjoining the liquid stream) during the EBCHR process. The cleaning beam may be generated by a pre-existing electron gun in a given EBCHR apparatus (e.g., FIG. 1 gun 15) or by an additional electron gun 410, which is provided, for example, in EBHCR apparatus 400 (FIG. 4). A programmable logic controller (PLC) 420 or similar programmable device may be used to control electron gun 410 and associated deflection optics (not shown) for moving cleaning beam 430 along a predetermined path. PLC 420 may be a stand alone controller or a controller which is in common with other electron guns (e.g., FIG. 1 electron gun 15) in the cold hearth arrangement.

The cleaning beam may be programmed to follow a path along the perimeter of the liquid stream in either the refining region and/or the melting region of the hearth. The co-ordinates of the path along the perimeter of the liquid stream are pre-recorded and utilized by the PLC 420 for this purpose. The path of the cleaning beam may be optimized for a given hearth and refining operation by empirical process learning. FIG. 5 schematically shows an exemplary path (50) of a cleaning beam along the perimeter of the liquid stream in refining region 18 and portions of melting region 17 of a prior art hearth 20 (which is also described in Harker, see e.g., Fig. 3 therein). The cleaning beam may traverse path 50 continuously or in step-and-scan mode in which the cleaning beam steps along a series of spots on each of which the cleaning beam stays for a "dwell time."

The cleaning beam directs energy to the skull surface to remelt, sublime, or reevaporate material that may condense as wings along the perimeter of the liquid stream. The

amount of energy delivered by the cleaning beam is a process parameter that may be suitably selected on consideration of the physiochemical properties (e.g., sublimation temperatures) of the material of concern (e.g., aluminum), and/or determined by empirical process learning. The amount of energy applied to a spot (e.g., spot 50a) along the scan path of the cleaning beam is a function of the intensity and the dwell time of the cleaning beam at the spot. In principle either parameter can be adjusted. In practice, however, it is more convenient to supply constant power to an electron gun keeping the intensity of the electron beam substantially fixed. The energy applied to a spot along the path of the cleaning beam then depends primarily on the dwell time of the electron beam. The co-ordinates of a spot and the dwell time of the electron beam at the spot are parameters that may be coded in a program (e.g., PLC program), which causes the electron beam to automatically sweep in a defined path along the perimeter of the liquid stream in the cold hearth. It will be understood that the sweep rate is also a programmable parameter that is suitably selected for keeping the perimeter of the liquid stream clean during the melting and refining operations. The sweep rate (like the dwell time and the spot co-ordinates) may be optimized, for example, by empirical process learning. For hearth dimensions like those mentioned, for example, with respect to FIG. 1, the sweep rate may be such that time it takes for the cleaning beam to circumscribe a path around the refining region may be in range from about a few milliseconds to several seconds. Exemplary dwell times of the cleaning beam at spots along the path may be in the range of about a millisecond to about several hundred milliseconds.

The automated cleaning of the perimeter of the liquid stream is likely to improve refined material throughput by eliminating flow interruptions caused by overgrown wings. Further, the automated perimeter cleaning is also likely to provide a consistent compositional

environment along the liquid stream during the refining operations. This consistent compositional environment can advantageously result in compositional uniformity of the refined material produced at different times during the refining operations.

Although the invention has been described herein with reference to specific embodiments, many modifications and variations therein will readily occur to those skilled in the art. Accordingly, all such variations and modifications are included within the intended scope of the invention.